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Summary of Thirty Years of Field Testing of MCH:

Antiaggregation Pheromone of the Spruce Bark Beetle and the Douglas-fir Beetle

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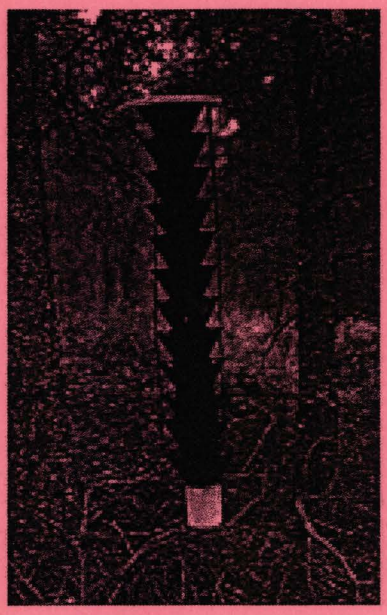

Technical Report R10-TP-91

March 2001

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Antiaggregation Pheromone of the Spruce Bark Beetle and the Douglas-fir Beetle

Technical Report R10-TP-91

March 2001

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ABSTRACT

MCH (3-methyl-2-cyclohexen-1-one), the antiaggregation pheromone produced by the Douglas-fir beetle and the spruce beetle, has been field-tested since the early 1970's for it's ability to suppress the build-up to damaging levels of these important forest pests. MCH is being used operationally for suppression of Douglas-fir beetle populations. Results of spruce beetle studies, however, have been inconsistent and inconclusive. Suggested factors contributing to these mixed results include micro-environmental influences and problems with release devices that dispensed the MCH. Questions remain as to the significance of MCH as a preventative for spruce beetle population growth.

INTRODUCTION

The spruce beetle, *Dendroctonus rufipennis* (Kirby), is a major destructive agent of mature, slow-growing spruce except black spruce (*Picea mariana* (Mill.) B.S.P.) throughout North America. In Alaska, the spruce beetle infests white (*P. glauca* (Moench) Voss), Sitka (*P. sitchensis* (Bong.) Carr), and Lutz spruce (*P. x lutzii* Little) (Werner and others 1977; Hard and Holsten 1985). The beetle has affected more than 4 million acres of spruce in Alaska in the past 20 years. Widespread loss of vast, contiguous stands of spruce, often encompassing entire watersheds, has major impacts on plant diversity, wildlife habitat, and forest productivity through stand conversion. Resultant fuel loading increases the possibility of catastrophic wildfire. Many areas of spruce beetle caused mortality occur within the urban/wildland interface, and in surrounding forested communities. Potential property loss from catastrophic wildfire is substantial. Furthermore, loss of timber on entire watersheds, subsequent increase in surface water runoff and sedimentation, and loss of the source of large woody debris may have adverse effects on salmon spawning habitat. Neither land managers nor the scientific community have addressed these issues in depth.

A number of factors contribute to the potential for bark beetle outbreaks, but the most important appears to be continual stressful environmental conditions under which the trees grow (Werner and others 1977, Hard 1985, 1987, Hard and others 1983). Stresses result from lack of silvicultural management (e.g., overstocked, old-aged stands), flooding, wildfire and windthrow events (Werner and others 1991). Weather and high temperatures within stands during the growing season (Werner and Holsten 1985) seem to be a contributing factor as well. Past outbreaks of spruce beetle activity in south-central Alaska have been associated with warm, dry summers; whereas, cool, moist summers had a marked damping effect on beetle activity.

Windthrown trees, large diameter logs and right-of–way slash are the most attractive breeding material for spruce beetles, and their progeny subsequently move into nearby weakened, injured or stressed standing trees.

The primary tools available to land managers to mitigate bark beetle impacts are either silvicultural (thinning, sanitation, harvest, etc.), prescribed fire in overstocked stands, or the use of chemicals (Hastings and others 2001). Pheromones are substances that are produced by and serve as chemical signals between members of the same species of bark beetle and when combined with tree host chemicals are called semiochemicals (Borden 1985). In the 1960's, research was begun on the synthesis of bark beetle pheromones.

These compounds include synthetic aggregation and anti-aggregation

pheromones. (Borden and others 1996, Holsten 1994, Salom and Hobson 1995, Shea 1994, Werner 1994, Werner and Holsten 1995, Werner and Holsten 1994, Werner and others 1991, Wieser and others 1989, 1991).

Bark beetles of the genus *Dendroctonus* manufacture at least four aggregation pheromones (Borden and others 1996), namely frontalin, seudenol, verbenone, and an analog of seudenol, MCOL (1-methyl-2-cyclohexen-1-ol). Response of beetles to any of these four compounds is enhanced if a host-tree terpene such as a-pinene, camphene or myrcene is also present. For the Douglas-fir beetle (*D. pseudotsugae* Hopkins), very dilute MCH (3-methyl-2-cyclohexen-1-one) strongly enhanced attractive effects of other pheromones in the aggregation mixture while undiluted MCH eliminated attraction almost entirely. Thus, MCH was called a masking pheromone (Ryker 1984).

MCH, thought to be the primary compound of the antiaggregation pheromone of the spruce beetle, was first identified by Kinzer and others (1971). It is naturally derived from female Douglas-fir and spruce beetles (Rudinsky and others 1974), and plays several roles in the pheromone complex of these species. Although MCH is a component of the attractive pheromone produced by the female Douglas-fir beetle (Rudinsky 1969, Rudinsky and others 1972), at higher release rates this compound appeared to interrupt beetle response to live trees baited with frontalin (Furniss and others 1972, Rudinsky and others 1972). Hedden and Pittman (1978) found that numbers of attacks initially decreased with an increase in MCH, but after minimum density was obtained, number of attacks increased and higher levels of MCH were required to maintain minimum number of attacks (Appendix 1). Rudinsky (1973) called this MCH a "multiple function" pheromone.

MCH also seems to play a role in courtship behavior and sound production of Douglas-fir beetles (Rudinsky and others 1973). The female releases MCH soon after entering a suitable host (Rudinsky 1966). As she initiates an egg gallery, she releases a small amount of MCH that increases the attractancy of the aggregation pheromone to approaching males (Rudinsky 1969). When the male responds to this attractant mixture, he releases a large quantity of MCH that serves as the chief stimulus for aggression (Pittman and Rudinsky 1974). Males possess larger quantities of MCH at emergence than females and are responsible for the greatest production of MCH, which is thought to regulate attack density and prevent over-crowding of attacked trees (Rudinsky and others 1973, Ryker 1984). Furniss and others (1974) confirmed the density regulating function of MCH. MCH plays another role in courtship as well. In the first step of courtship, the male releases MCH that initiates the aggressive phase of courtship. Apparently, release of MCH during the mating process signals rival males to disperse further in search of a mating partner.

In light of it's apparent role in similar behavioral modification of spruce beetle populations, synthesis of MCH provided researchers with a promising new tool for manipulating spruce beetle populations. Treating windthrown timber or large diameter slash with MCH would hopefully prevent buildup of beetles in this material and reduce spread of beetles into surrounding, standing trees.

OBJECTIVE

The objective of this report is to summarize the results of nearly 30 years of MCH field-testing in the western United States, Alaska and western Canada. The following is discussed chronologically by bark beetle species and followed by a discussion of release rates and pheromone dispersion research.

DISCUSSION

Douglas-fir beetle

In 1971, MCH, in a liquid formulation, was tested against the Douglas-fir beetle in Oregon and Idaho in windthrown, standing, weakened and freshly felled Douglas-fir. MCH reduced attractiveness of suitable host material by 82-86%. In Oregon the addition of MCH to attractive pheromones resulted in a consistent, pronounced decrease in the ratio of males to females. The ratio of males to females averaged 7.5 with most frontalin treatments alone but only 1.9 when MCH was added. The biological significance of this change in the sex-ratio is unknown (Rudinsky and others 1972) (Appendix 1). In 1972, Furniss and others (1974) tested liquid MCH in Oregon, Idaho and Washington to protect felled Douglas-fir from attack by the Douglas-fir beetle and found that trees treated with MCH had 96% fewer attacks and 91% fewer progeny than did untreated trees (Furniss and others 1974) (Appendix 1).

In 1973, Rudinsky and others (1974) continued his earlier work with MCH in Oregon on windthrown Douglas-fir against the Douglas-fir beetle. Both granular and liquid formulations of MCH were employed. The granular formulation was applied using a uniform hand-spreading method while 90 mg of liquid MCH was dispensed in ½ dram glass vials which were, in turn, placed in perforated film canisters. Almost complete protection was afforded by the vials of liquid MCH placed at 1.8 m intervals along the bole of the tree, 25 vials on each side of the tree. The granular treatment (3.8% formulation with a 1x dosage of 135 g) resulted in an average of 0.35 attacks/sq. ft.

compared to 1.1 in control trees (Appendix 1).

The results of these tests and others (Appendix 1) demonstrated that MCH held promise as a management tool for reducing potential increases in populations of Douglas-fir and spruce beetles. The liquid formulation method of delivery, however, was impractical to use operationally over larger tracts of land. Development of controlled release formulations began and in 1975, Furniss and others (1977) field-tested five controlled release granular formulations containing 2% MCH for their effectiveness against Douglas-fir beetle in Idaho. The formulations differed only in the inert components used to "carry" MCH. The inert components consisted either of a wax-coated molecular sieve, polyethylene emulsion-coated ground corncob, or dimer acid polyamide beads. Attack density was significantly reduced by the molecular sieve formulation and the liquid standard placed in cans on stakes 4 ft. above ground and by the dimer acid polyamid beads broadcast by hand. Brood density was reduced by the molecular sieve formulation, the liquid standard and by one of the dimer acid polyamid bead formulations broadcast by hand (Appendix 1). When a controlled release granular formulation of MCH was applied by helicopter, Douglas-fir beetle attacks were reduced 92-97% and progeny reduced 93-99% in felled trees (Furniss and others 1981).

Release devices known as bubble caps were developed at the Department of Chemical Engineering at the University of British Columbia. Pheromone release rates could be adjusted by altering thickness and density of a semi permeable plastic membrane through which the chemical is released. Bubble caps are easily stapled to the bole of standing or windthrown trees.

Ross and Daterman (1995) reduced populations of Douglas-fir beetles in high risk stands using MCH bubble caps with a "push" and "pull" technique, where aggregation pheromones are used in conjunction with antiaggregation pheromones. They also conducted field tests to determine the optimal dose and rates of elution of MCH from bubble caps (Ross and others 1996).

MCH bubble caps were re-tested in 1991 in Idaho on live Douglas-fir for control of Douglas-fir beetle and in Idaho and Utah on standing Engelmann spruce for spruce beetle control (Their 1993;Their and Munson 1993) (Appendix 1). The spruce beetle test produced no significant reduction in activity which was thought to be caused by an inadequate number of release devices. The test in a Douglas-fir stand also failed because of very low beetle populations.

Spruce beetle

In 1973, Rudinsky and others (1974) tested both granular and liquid formulations

of MCH against spruce beetle on Sitka spruce in Oregon. Liquid MCH deployed in glass vials placed in perforated film canisters resulted in complete protection from attack (0.01 attacks/sq. ft. on treated trees compared to 1.57/sq. ft. on untreated controls).

Next in protective value was the 3.6% granular formulation at 10x dosage, 1350g/tree, which completely protected logs during the first two flight periods. At the end of the test (eight weeks) there were only ¼ as many attacks on treated vs. untreated control trees, a 93.3% reduction of attacks for a period of five weeks (Appendix 1).

Kline and others (1974) tested liquid MCH against spruce beetle in Idaho and reduced attractiveness to infested logs by 99% (Appendix 1). MCH reduced spruce beetle attacks by 50% in white spruce stumps when released from two glass vials (0.1 ml/vial) per stump (Dyer and Lawko 1978). Although significantly fewer attacks occurred on untreated stumps, the attack density was not significantly different to be of practical value in controlling spruce beetle reproduction.

Field testing of MCH to control spruce beetle populations was done in Alaska at the same time tests using MCH were underway in Idaho and Montana to control Douglas-fir beetle (McGregor and others 1984, 1985). Bubble caps were used in the Douglas-fir field tests; whereas, granular MCH and liquid MCH, dispersed from glass vials, were used in the Alaskan tests. Results of these Alaskan tests were inconsistent regardless of dosages or formulations. Apparently low temperatures contributed to inadequate elution rates of MCH from both bubble caps and granular formulations (Holsten and Werner 1984) (Appendix 1).

Two MCH field studies were conducted in 1976 on the Kenai Peninsula, Alaska, an area of expanding spruce beetle populations. In one study, liquid MCH in glass vials was compared against 2% MCH in a controlled release bead formulation applied at the rate of 4.6 kg/ha. By the time MCH was applied, the beetles had already begun to disperse and the average densities of spruce beetle attacks and progeny did not differ significantly by treatment (Furniss and others 1979). Lack of treatment effect was thought to be due to a lower than desired elution rate of MCH, which was only one half of that which was sought. Cool temperatures in the study area were suspected as the cause. In the second test, liquid MCH was used to reduce attraction to female infested logs and screened sticky traps baited with seudenol and alpha pinene. The results showed that MCH repressed attraction of additional beetles to female infested logs by 87% and to the seudenol and alpha pinene baited traps by 99% (Furniss and others 1974) (Appendix 1).

A 2% controlled release granular formulation of MCH applied at 4.6, 9.2 and

13.8 kg/ha was tested in Alaska in 1983. These granular formulations had elution rates of 0.25, 0.50 and 0.75 g/ha/day, compared to three formulations of liquid MCH (150, 300 and 450mg of MCH) released at 1.2, 2.4 and 4.8 mg/ha/day. Results indicated that the high dose liquid treatment and the 9.2 kg/ha dosage rate of granular MCH significantly reduced attack density, gallery length and progeny compared to the controls, but not from one another (Holsten and Werner 1984) (Appendix 1).

Granular formulations of MCH tested in Alaska (Furniss 1979; Mask 1995; Holsten and others 1992, Werner 1994, Werner and Holsten 1995, Werner and others 1991) (Appendix 1) produced disappointing results because beetle pressure was either too low, or, because elution rates were thought to be reduced by cool soil / litter temperatures (Appendix 1).

Another Alaskan test, bubble caps identical to those used in the Montana study (Lindgren and McGregor 1989) were formulated to release MCH at the rate of 0.5 mg/24 hours and were applied at spacings of 1.5 and 3 m between bubble caps along the upper boles of felled white spruce trees. There were no significant differences between bubble cap spacing treatments and controls (Holsten and Werner 1985) (Appendix 1). Again, lower than expected MCH release rates were suspected, in part, for the lack of reduction in spruce beetle attacks. Membrane used in the caps was calibrated to release at 20°C, but temperatures at the study site seldom reached this temperature. Average mean daily temperature from the end of May through the first week in July, the period of peak beetle flight in Alaska, was 11°C (Holsten and Werner, 1985) (Appendix 1).

MCH bubble caps were tested again in 1986, but formulated to elute at 16°C, near the 14.5°C flight threshold temperature for spruce beetles in Alaska (Werner and Holsten 1984, 1985). Three release rates were tested; 1, 3 and 5 mg MCH/day. There was a significant reduction in attacks by 43-53% and gallery length was reduced significantly. There was no effect on progeny or number of egg galleries (Holsten and Werner 1987) (Appendix 1). All three treatments significantly reduced gallery length as compared to untreated trees (Holsten and Werner 1987) (Appendix 1).

Lindgren and others (1989) tested MCH bubble caps for spruce beetle control in Montana in 1984 in both felled Engelmann spruce (*P. engelmannii* Parry) and on baited funnel traps. Three treatments were employed: 1) six felled spruce as controls; 2) six felled spruce with one baited funnel trap located at each corner of the plot and 3) six felled spruce, three with 15 MCH bubble caps (1 cap/ 1.5 m of bole length) and three with 9 MCH bubble caps (1 cap/ 3 m of bole length) and a baited trap located in each corner of the plot. The MCH and funnel trap treatment reduced the number of attacks by 62.5% and the attack density by 75.9%. There was no difference in total attacks or

attack density between the two spacings of MCH within the MCH plus traps treatment. The percent successful attacks in the MCH plus traps treatment was significantly lower than in the other treatments. However, treatment effect was lower than anticipated and thought to be caused, in part, to breakdown of the bubble cap membrane on exposure to UV light. New bubble caps with a protective cover to avoid further membrane deterioration were installed, but most attacks had already occurred (Lindgren and others 1985) (Appendix 1).

Research using bubble caps to protect stands of Lutz and Sitka spruce on the Kenai Peninsula and southeast Alaska was continued for 5 years. Both circular and square plots and individual trees were treated with bubble caps containing MCH or methyl chavical. Werner (1994) tested MCH and methyl chavical bubble caps formulated to release at 17 and 24°C at a rate of 16 and 25 bubble caps per half acre in stands of Lutz spruce in south-central Alaska. There was no significant difference between treatment plots and control plots due to the large variability between replications. The percentages of attacked vs. unattacked trees, however, showed positive effects for the 17°C MCH bubble caps applied at the rate of 25 per half acre. Results from these field tests have been published in several reports (Holsten 1994, Werner 1994, Werner and Holsten 1995, Werner and others 1996b).

Mask (1995) tested MCH bubble caps in an attempt to reduce spruce beetle attacks on live, standing and windthrown Sitka spruce near Haines, Alaska. Bubble caps containing 400 mg MCH formulated to release at 17°C were evenly spaced at 16 or 25 caps per half acre and stapled directly to standing trees. On windthrown trees, two bubble caps were stapled to the tree, one at 20' and one at 60' from the root collar. No significant reductions in either number of attacks or brood were observed. Lack of treatment effects were attributed to lack of adequate beetle pressure near standing trees and, in the windthrow area, by the limited influence of MCH overwhelmed by many acres of windthrown spruce (Mask 1995) (Appendix 1).

Hard (1998) tested 17°C bubble caps in both thinned and unthinned stands for the prevention of spruce beetle attacks in standing Lutz spruce as well as reducing the number of attacks in already infested trees. There was no significant effect with the MCH treatments (Appendix 1).

In an effort to overcome the problem of micro-environmental influences on elution rates of pheromones from bubble caps and granular formulations, a new release device is being developed by Med-E-Cell®. It uses a chemical pump to deliver a pheromone at a precisely metered rate. A preliminary Alaska field trial in 1999 using a small number of these devices containing MCH employed in baited funnel traps, showed promise.

In May 2000 a replicated field study was undertaken in Alaska to determine if Med-E-Cell^{R} MCH release devices could significantly reduce the number of attacked spruce compared to untreated trees. Twenty-one, one-half acre plots were each randomly assigned to one of the three treatments: untreated check plot; circular plot treated with 25 release devices placed in two concentric circles, one near the outer boundary of the plot and one half-way distant from center; and square plot treated with 25 release devices spaced evenly throughout the plot. Spruce beetle pressure was low in the study area. Accordingly, a three component spruce beetle attractant was placed in the center of each plot to "pull" beetles into the study area. Med-E-Cell^{R} devices eluting MCH at a controlled rate significantly reduced the number of new spruce beetle attacks in treated plots as compared to the check plots. On a per acre basis, check plots averaged 11 attacked trees, circular plots, 2.2 and square plots, 1.5. There was no significant difference between circular or square plots (Holsten 2000; unpublished data). Attack densities were too low for this test to be considered definitive. The test will be repeated in a more active spruce beetle infestation (Appendix 1).

Release rates and pheromone dispersion

The production of MCH from artificially and naturally infested Lutz spruce by the spruce beetle was determined from laboratory studies undertaken in south-central Alaska (Holsten and others 2001). The amount of MCH produced from five infested trees was estimated to be 54 to 174 micrograms/acre/day. The higher amount of MCH was produced from spruce beetles introduced into Lutz spruce bolts that were "aged" for eight months prior to beetle attack.

As a result of inadequacy of release devices to respond effectively in differing microclimates, Holsten and others (2001) quantified the effects of temperature on elution rates of MCH from bubble caps and granular formulations. The test was done at two sites each in California, Oregon and Alaska. MCH bubble caps with a 24°C release rate membrane were used at all sites; 17°C release bubble caps were also used at the Alaskan sites (Werner and others 1995a). Prior tests indicated that the17^{0}C bubble cap was significantly more effective at cooler Alaskan temperatures (Werner 1994, Werner and Holsten 1995, Werner and others 1991, 1995a,b). Granular formulations of 2.1% MCH and 2.6% verbenone were distributed on the forest floor at the California sites. Verbenone is the antiaggregation pheromone of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (Borden 1995).

Results of this study showed that elution rates from both devices varied greatly. The fastest elution rate from bubble caps occurred at a warm, California pine site and

was 15 times the rate at the cool, Seward spruce site in Alaska. This may be caused either by resistance of the membrane or by vapor pressure to membrane fouling that impeded the release of MCH (Werner and others 1995a). Elution rate is controlled by saturation vapor pressure that increases exponentially with temperature. Total encapsulated amount of MCH did not elute from beads. Beads quickly released MCH for approximately two weeks followed by little to no elution regardless of the amount of pheromone remaining in the beads, or of litter layer temperature. Initial mass of MCH per bead was 0.835 mg +/- 0.181 mg standard deviation. The lowest amount observed was 0.384 mg and the highest was 1.16 mg. Residual mass of MCH at selected sites was as follows: Darling, CA, 0.17 mg; Silver Forks, CA, 0.10 mg; Seward, AK, 0.25 mg and Cooper Landing, AK, 0.5 mg.

Most bark beetle pheromone research and operational use relies on passive pheromone dispersion in a forested environment. For this approach to be successful, a gaseous concentration of pheromone must exist in the air around the insect in sufficient quantities to elicit a response from the insect. Studies are currently underway to quantify the dispersion of a gas released in the canopy trunk space simulating the dispersion of the pheromone (Thistle and others 1999). Results are preliminary from these on-going studies but are beginning to allow the development of guidance for the placement of passive pheromone dispensers under a forest canopy.

CONCLUSIONS

MCH appears to work quite well against the Douglas-fir beetle. Ross reports that over 20,000 acres of Douglas-fir in Washington, Oregon, Idaho and Montana were treated with MCH bubblecaps operationally in 2000 to prevent build up of Douglas-fir beetle. There were no reports of unsatisfactory results (Ross, personal communication, 2001). The results of field-tests using MCH to suppress spruce beetle populations, however, are inconclusive. Factors accounting for lack of consistent results when using MCH for spruce beetle control are poorly understood. MCH may not be as strong an antiaggregative element in the spruce beetle complex of pheromones compared to the Douglas-fir beetle. Possibly another, as yet elucidated compound, is required in addition to MCH to achieve desired effects.

It is not clear why MCH seems to work consistently against spruce beetle when used in baited funnel traps, but inconsistently when used in bubble caps attached directly to the tree, or, when dispersed throughout the stand in granular, slow-release formulations. Perhaps new technologies or refinement of existing dispersal devices will remove some of the variability encountered in field trials.

Additional laboratory bioassays comparing responses of the Douglas-fir and spruce beetle to various combinations and dosages of MCH and other semiochemicals may also be required to shed further light on the problem.

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APPENDIX 1--SYNOPSIS OF MCH FIELD STUDIES IN THE PACIFIC NORTHWEST, ALASKA, AND CANADA

SITE: Oregon, Idaho
DATE: May 1971
RELEASE DEVICE: liquid MCH in ½ dram glass vial inside aluminum film canister with seven, 1/16-in.-diameter perforations in bottom
RELEASE RATE: 0.5 – 0.9 mg/hr
DOSAGE: 20 mg liquid MCH
HOST: standing weakened, windthrown and freshly felled Douglas-fir
RESULTS: Attractiveness decreased 82-86% and m/f sex ratio was reduced from 7.5 to 1.9
REFERENCE: Rudinsky et al., 1972. Can. Ent. 104: 815 – 822

SITE: Idaho, Oregon, Washington
DATE: May 1972
RELEASE DEVICE: liquid MCH in tubes or vials in perforated aluminum film canisters and glass jars in perforated iron cans
RELEASE RATE: 0.1x dose = 0.12 mg/day; field elution rates 2 – 3x that of lab rates
DOSAGE: optimum treatment was ca. 1 – 2 mg/day at 10' spacing (0.06 – 1.3 g/ac/day)
HOST: felled Douglas-fir
RESULTS: Number of attacks and progeny reduced by 91 and 96% respectively
REFERENCE: Furniss et al. 1974. Can. Ent. 106: 381 – 392

SITE: Idaho
DATE: May 1972
RELEASE DEVICE: liquid MCH in ½ dram glass vial inside aluminum film canister with seven, 1/16-in.-diameter perforations in bottom
RELEASE RATE: unavailable
DOSAGE: 20 mg liquid MCH
HOST: log sections infested with 40 unmated females
RESULTS: Attraction to infested logs reduced 99%; attractant-baited traps nullified by addition of MCH
REFERENCE: Kline et al., 1974. Can. Ent. 106: 485 – 491

SITE: Idaho
DATE: May 1973
RELEASE DEVICE: liquid MCH in caps, tubes and bottles
RELEASE RATE: test #1: 0.9 – 1.5 mg/hr/plot; test #2: 0.0 – 2.64 mg/hr
DOSAGE: 1 – 2 ml/vial
HOST: standing Douglas-fir
RESULTS: MCH caused decrease in number of attacks when eluting at 2 – 3 mg/hr
REFERENCE: Hedden et al., 1978. J. Econ. Entomol. 78: 633 – 637

SITE: Oregon

DATE: March 1973

RELEASE DEVICE: liquid MCH in ½ dram glass vials inside aluminum film canisters with seven, 1/16-in.-diameter perforations in bottom and MCH in a slow release granular formulation

RELEASE RATE: liquid MCH = 0.7 mg/day

DOSAGE: 135g of 3.60% granular MCH / tree; 1350g granular MCH / tree; 90 mg liquid MCH/vial

HOST: windthrown and freshly felled Sitka spruce and Douglas-fir

RESULTS: 1350g / tree offered full protection for one month; 135g / tree = no significant difference; liquid MCH = almost complete protection

REFERENCE: Rudinsky et al., 1974. Z. ang. Ent. 75: 254 – 63

SITE: Idaho

DATE: May 1975

RELEASE DEVICE: 5 granular formulations; liquid MCH in ½ dram glass vials within aluminum film canisters with seven, 1/16-in.-diameter perforations in bottom

RELEASE RATE: variable, but close to 1 ug/h in the lab

DOSAGE: granular dosage 4.1 lb/acre (38 g/acre actual MCH); 300 mg liquid MCH in glass vials

HOST: felled Douglas-fir

RESULTS: Significant reduction in Douglas-fir beetle attacks for all treatments; significant reduction in brood in three treatments

REFERENCE: Furniss et al., 1977. Can. Ent. 109: 1063 – 1069

SITE: British Columbia

DATE: 1975

RELEASE DEVICE: open ½ dram vial with 3, 2-MCH within a closed, perforated film can; open ½ dram vial with *trans*-verbenol within closed, perforated film can

RELEASE RATE: not available

DOSAGE: 0.1 ml MCH/vial; 0.15 ml *trans*-verbenol/vial

HOST: winter cut spruce stumps

RESULTS: MCH and MCH+*trans*-verbenol reduced attacks but not significantly. Only 50% reduction in attack density with spacing <1m. Not enough to reduce population in next generation.

REFERENCE: Dyer and Hall, 1977. J. Ent. Soc. Brit. Columbia 74: 32 – 33.

SITE: Alaska

DATE: 1977

RELEASE DEVICE: liquid MCH in open glass vials; granular formulation

RELEASE RATE: not available

DOSAGE: liquid, not available; granular = 2% MCH at 4.6 kg/ha

HOST: felled white spruce

RESULTS: No significant difference in attack density by treatment; low elution rate due to temperature

REFERENCE: Furniss et al., 1979. Can Ent. 111: 1355 – 60

SITE: Idaho

DATE: March 1979

RELEASE DEVICE: granular / helicopter

RELEASE RATE: not available

DOSAGE: 1.96 kg/ha (range = 1.41 – 2.61); 6.8 kg/ha (range = 4.19 – 9.80)

HOST: freshly felled Douglas-fir

RESULTS: May: attack density reduced 95 and 97%, higher rate had 42% fewer infested trees; August: attack density reduced 93-99%. Progeny reduced 92-99%. Higher rate reduced attacks more than lower rate, but no significant difference

REFERENCE: Furniss et al., 1981. USDA For. Ser. Rpt. GTR-INT-101

SITE: Idaho

DATE: May 1982

RELEASE DEVICE: granular / helicopter

RELEASE RATE: not available

DOSAGE: 2.04 – 2.69 kg/ha

HOST: spruce beetle: windthrown Engelmann spruce; Douglas-fir beetle: windthrown Douglas-fir

RESULTS: Spruce beetle attacks 0.79 per 0.1 m^2 in treated plots vs. 3.96 per 0.1 m^2 in untreated plots. Douglas-fir beetle attacks reduced by ~96.4%

REFERENCE: McGregor et al., 1984. Journal of Forestry Vol. 82, No. 10, p. 613 – 616

SITE: Idaho

DATE: May 1982

RELEASE DEVICE: granular / helicopter

RELEASE RATE: not available

DOSAGE: 4.48 kg/ha

HOST: windthrown Douglas-fir

RESULTS: Population reduced 96.4%. No successful attacks for 2 years. Good protection in adjacent stands.

REFERENCE: McGregor et al., 1984. USDA For. Ser. Rpt. FPM Rpt. 85-7

SITE: Alaska

DATE: May 1983

RELEASE DEVICE: liquid MCH in open glass vials; granules

RELEASE RATE: granular: 2.6 $\pm$ 2.2 mg/day, 5.3 $\pm$ 4.2 mg/day, 10.2 $\pm$ 8.3 mg/day; liquid: 1.6 $\pm$ 0.9 mg/day, 2.9 $\pm$ 1.1 mg/day, 4.3 $\pm$ 1.3 mg/day

DOSAGE: granular: 4.6 kg/ha, 9.2 kg/ha, 13.8 kg/ha; liquid: 150 mg, 300 mg, 450 mg

HOST: felled white spruce

RESULTS: Best treatment: 450 mg liquid MCH and 9.2 kg/ha granular reduced spruce beetle attacks and progeny by 70 and 61% respectively. Microclimate/environmental factors probably reduced elution rates.

REFERENCE: Holsten and Werner, 1984. USDA For. Ser. Rpt. FPM Rpt. R10-6 (3-84)

SITE: Montana

DATE: May 1984

RELEASE DEVICE: bubble caps on trees and bubble caps on baited traps

RELEASE RATE: 1 – 3 mg/day @ 20^0C

DOSAGE: 9 or 15 bubble caps/tree; 1 bubble cap/trap

HOST: felled Engelmann spruce and attractant baited traps

RESULTS: Attack density reduced 10-25% with either 9 or 15 bubble caps. Number of attacks reduced 85%. Brood production reduced 79-88% in felled trees.

REFERENCE: Lindgren et al., 1989. West. J. App. For. 4(2): 49 – 52

SITE: Alaska

DATE: May 1984

RELEASE DEVICE: granular

RELEASE RATE: 3.7 mg/ha/day $\pm$ 5.3 mg/ha/day

DOSAGE: 6.9, 9.2, 11.5 kg/ha

HOST: felled white spruce

RESULTS: No significant difference between treated vs. controls. Low elution rates possibly due to microclimatic conditions.

REFERENCE: Holsten et al., 1985. USDA For. Ser. Rpt FPM Rpt. R10-9 (2-85)

SITE: Alaska

DATE: May 1985

RELEASE DEVICE: bubble caps

RELEASE RATE: 0.9 mg/day @ 20^0C

DOSAGE: 1.5 and 3m spacing along upper bole of felled spruce trees

HOST: felled white spruce

RESULTS: No significant difference between treated vs. controls. UV breakdown of membrane. Low temperatures probably reduced elution rates

REFERENCE: Holsten and Werner, 1985. USDA For. Ser. Rpt. FPM Rpt. R10-12 (10-85)

SITE: Alaska

DATE: May 1986

RELEASE DEVICE: bubble caps

RELEASE RATE: 1.0, 3.0, 5.0 mg/day @ 16^0C

DOSAGE: caps spaced at 1.5m intervals along bole of unlimbed, felled white spruce

HOST: felled white spruce

RESULTS: Significant reduction in attacks by 43-53%. Gallery length reduced significantly. No effect on progeny or number of egg galleries. No significant difference among MCH treatments.

REFERENCE: Holsten and Werner, 1987. USDA For. Ser. Rpt. FPM Rpt. R10-14 (4-87)

SITE: Idaho

DATE: 1991

RELEASE DEVICE: bubble caps

RELEASE RATE: 0.5 mg/day

DOSAGE: 40 caps/ac. in a grid pattern

HOST: standing, live Douglas-fir

RESULTS: No testable results due to low beetle populations

REFERENCE: Their, 1993. USDA For. Ser. Rpt. FPM Rpt. R4-93-03

SITE: Alaska

DATE: May 1991

RELEASE DEVICE: granular (aerial and ground application)

RELEASE RATE: 0.25 – 2.5 g MCH/ha/day

DOSAGE: aerial: 4.6 and 9.2 kg/ha; ground: 9.2 and 13.6 kg/ha

HOST: right-of-way clearing debris in Lutz spruce

RESULTS: No significant difference in number of attacks or progeny. Beetle pressure too low to test effectiveness.

REFERENCE: Holsten et al., 1992. USDA For. Ser. Rpt. FPM Rpt. R10-TP-23 (2-92)

SITE: Idaho, Utah

DATE: 1990-91

RELEASE DEVICE: bubble caps

RELEASE RATE: 0.5 mg MCH/day

DOSAGE: 40 bubble caps/ac in a grid pattern

HOST: standing Engelmann spruce

RESULTS: No significant difference but treated plots sustained fewer spruce beetle attacks than untreated (5.4 vs. 9.2 or 1.3% vs. 16.5%)

REFERENCE: Their and Munson, 1993. USDA For. Ser. Rpt. FPM Rpt. R4-93-02

SITE: Oregon

DATE: April 1993

RELEASE DEVICE: bubble caps

RELEASE RATE: 1.46 mg/day. Plot with lowest density of caps, 0.16 g/ha/day

DOSAGE: 400 mg bubble caps. 138 $\pm$ caps/ac; Range 113 – 189 caps

HOST: stands of high risk Douglas-fir

RESULTS: MCH significantly reduced mass attacks

REFERENCE: Ross and Daterman, 1995. Can. Ent. 127: 805-811

SITE: Alaska

DATE: May 1993

RELEASE DEVICE: granular

RELEASE RATE: not available

DOSAGE: 12.3 lb/ac and 8.2 lb/ac

HOST: windthrown Sitka spruce

RESULTS: Neither rate successful in reducing number of attacks or number of brood

REFERENCE: Mask, 1995. USDA For. Ser. Rpt. FPM Rpt. R10-TP-52

SITE: Oregon, Montana, Idaho, Utah

DATE: 1994-95

RELEASE DEVICE: bubble caps

RELEASE RATE: 1.63 $\pm$ 0.07 mg/day; 1.23 $\pm$ 0.05 mg/day

DOSAGE: 50, 100, 150 caps/ac; 15, 30, 50 caps/ac

HOST: standing, high-risk Douglas-fir

RESULTS: All three doses equally effective at preventing mass attacks and reducing numbers of Douglas-fir beetles caught in traps in 1994. in 1995, no significant difference in % mass attacks. MCH at 20 g/ac effective in protecting Douglas-fir from attack by Douglas-fir beetle.

REFERENCE: Ross et al., 1996. J. Econ. Entomol. 89(5): 1204 – 1207

SITE: Alaska

DATE: May 1994

RELEASE DEVICE: bubble caps

RELEASE RATE: not available

DOSAGE: 17^{0}C bubble caps with 400 mg MCH. 2 caps/tree in blowdown. In standing trees, 16-25 caps/half acre.

HOST: windthrown and standing Sitka spruce

RESULTS: No significant difference in number of attacks or brood. Numbers were inversely related to number of bubble caps.

REFERENCE: Mask, 1995. USDA For. Ser. Rpt. FPM Rpt. R10-TP-54

SITE: Alaska

DATE: May 1994

RELEASE DEVICE: bubble caps

RELEASE RATE: not available

DOSAGE: 16 MCH bubble caps @ 17^{0}C; 16 MCH bubble caps @ 24^{0}C; 25 MCH bubble caps @ 17^{0}C; 25 MCH bubble caps @ 24^{0}C; 25 MC bubble caps @ 17^{0}C; 25 MC bubble caps @ 24^{0}C (all per ½ acre).

HOST: standing Lutz spruce

RESULTS: No difference between treated and control plots due to large variability between replications, but %'s of attacked vs. unattacked trees showed positive effects for the 25 MCH @ 17^{0}C treatment.

REFERENCE: Werner et al., 1994. TDP project R10-94-01. Unpublished data.

SITE: Alaska

DATE: May 1994

RELEASE DEVICE: bubble caps

RELEASE RATE: not available

DOSAGE: 25 MCH bubble caps @ 17^{0}C/half acre plot

HOST: standing Lutz spruce (single tree protection study)

RESULTS: No difference between treatments. Check trees too lightly attacked to demonstrate treatment effect

REFERENCE: Werner et al., 1994. TDP project R10-94-01. Unpublished data.

SITE: Alaska

DATE: May 1995

RELEASE DEVICE: bubble caps

RELEASE RATE: not available

DOSAGE: 2 MCH bubble caps @ 17^{0}C per tree

HOST: standing Lutz spruce (single tree protection study)

RESULTS: No treatment effect could be demonstrated because no check trees were attacked

REFERENCE: Werner et al., 1994. TDP project R10-94-01. Unpublished data.

SITE: Alaska

DATE: May 1996

RELEASE DEVICE: bubble caps

RELEASE RATE: not available

DOSAGE: 25 MCH bubble caps @ 17^{0}C/ half acre square and round plots

HOST: standing Lutz spruce (stand protection study)

RESULTS: %'s of attacked trees of control plots compared to MCH treated plots show positive effects for the application of MCH bubble caps to both round and square plots.

REFERENCE: Werner et al., 1994. TDP project R10-94-01. Unpublished data.

SITE: Alaska

DATE: May 1998

RELEASE DEVICE: bubble caps

RELEASE RATE: not available

DOSAGE: attack prevention study: 1 MCH bubble cap @ 17^{0}C / 8" of tree diameter; attack abatement study: 1 or 2 MCH bubble caps @ 17^{0}C

HOST: standing Lutz spruce

RESULTS: No significant difference between treatments

REFERENCE: Hard, 1998. Unpublished data.

SITE: Alaska

DATE: May 2000

RELEASE DEVICE: chemical pump

RELEASE RATE:

DOSAGE: 25 pumps per square plot placed in a grid pattern or 25 pumps per circular plot placed in 2 concentric circles within the plot.

HOST: standing Lutz and Sitka spruce

RESULTS: Significant reduction in number of new spruce beetle attacks in treated plots compared to check plots, but no significant difference between square or circular plots. Attack densities were too low for this test to be considered definitive. Test will be repeated in a more active beetle infestation.

REFERENCE: Holsten, 2000. Unpublished data.